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Standard Specification for Castings, Investment, Carbon and Low Alloy Steel for General Application, and Cobalt Alloy for High Strength at Elevated Temperatures[1]

This standard is issued under the fixed designation A 732/A732M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers carbon and low-alloy steel castings made by the investment casting process.

1.2 Fifteen grades of steel and two cobalt alloy grades are covered (see Appendix).

NOTE 1—An investment casting is one that is produced in a mold, obtained by investing (surrounding) an expendable pattern with a refractory slurry which is allowed to solidify. The expendable pattern may consist of wax, plastic, or other material and is removed by heating prior to filling the mold with liquid metal.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 488/A488M Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel[3]

A 919 Terminology Relating to Heat Treatment of Metals[3]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[4]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[5]

E 94 Guide for Radiographic Testing[6]

E 125 Reference Photographs for Magnetic Particle Indications on Ferrous Castings[6]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[4]

E 165 Test Method for Liquid Penetrant Examination[6]

E 192 Reference Radiographs of Investment Steel Castings for Aerospace Applications[6]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[5]

E 446 Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness[6]

E 709 Guide for Magnetic Particle Examination[6]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Description of the casting by part or pattern number or drawing,

3.1.2 ASTM designation and year of issue,

3.1.3 Grade of steel,

3.1.4 Quantity,

3.1.5 Options in the specification (4.1, 5.3, 6.1, 9.1, and 10.3), and

3.1.6 Supplementary requirements.

4. Heat Treatment

4.1 Castings shall be supplied in the heat-treated condition with the exception of Grades 21 and 31. Heat treatment shall be either annealing, normalizing and tempering, or quenching and tempering to obtain either the specified properties or other properties that might be agreed upon within each grade. In this latter instance, Supplementary Requirement S19 should be used. Grades 21 and 31 shall be supplied in the as-cast condition unless otherwise agreed upon.

4.2 Heat treatment shall be performed after the castings have been allowed to cool below the transformation range.

4.3 Definitions of terms relating to heat treatment shall be in accordance with Terminology A 919.

5. Chemical Composition

5.1 The castings shall conform to the requirements for chemical composition specified in Table 1 and Table 2.

5.2 *Cast or Heat Analysis*—An analysis of each cast or heat shall be made by the manufacturer to determine the percentages of the elements specified in Table 1 and Table 2. The

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[2] *Annual Book of ASTM Standards*, Vols 01.02 and 01.03.

[3] *Annual Book of ASTM Standards*, Vol 01.02.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.05.

[6] *Annual Book of ASTM Standards*, Vol 03.03.

TABLE 1 Chemical Requirements

Grade	1A	2A,2Q	3A,3Q	4A,4Q	5N	6N	7Q	8Q
Type	Low Carbon IC 1020[A]	Medium Carbon IC 1030	Medium Carbon IC 1040	Medium Carbon IC 1050	Vanadium IC 6120	Manganese Molybdenum IC 4020	Chromium Molybdenum IC 4130	Chromium Molybdenum IC 4140
Carbon	0.15 to 0.25	0.25 to 0.35	0.35 to 0.45	0.45 to 0.55	0.30 max	0.35 max	0.25 to 0.35	0.35 to 0.45
Manganese	0.20 to 0.60	0.70 to 1.00	0.70 to 1.00	0.70 to 1.00	0.70 to 1.00	1.35 to 1.75	0.40 to 0.70	0.70 to 1.00
Phosphorus, max	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sulfur, max	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Silicon	0.20 to 1.00	0.20 to 1.00	0.20 to 1.00	0.20 to 1.00	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80
Nickel	...	...	...	...	...	...	...	...
Chromium	...	...	...	...	...	...	0.80 to 1.10	0.80 to 1.10
Molybdenum	...	...	...	...	...	0.25 to 0.55	0.15 to 0.25	0.15 to 0.25
Vanadium	...	...	...	...	0.05 to 0.15	...	...	...
Residual Elements:								
Copper	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nickel	0.50	0.50	0.50	...	0.50	0.50	...	0.50
Chromium	0.35	0.35	0.35	...	0.35	0.35	...	...
Molybdenum + Tungsten	0.25	...	...	...	0.25	...	...	...
Tungsten	...	0.10	0.10	0.10	...	0.25	0.10	0.10
Total content of unspecified elements	1.00	1.00	1.00	0.60	1.00	1.00	0.60	1.00

Grade	9Q	10Q	11Q	12Q	13Q	14Q	15A
Type	Chrome Nickel Molybdenum IC 4330	Chrome Nickel Molybdenum IC 4340	Nickel Molybdenum IC 4620	Chromium Vanadium IC 6150	Chrome Nickel Molybdenum IC 8620	Chrome Nickel Molybdenum IC 8630	Chromium IC 52100
Carbon	0.25 to 0.35	0.35 to 0.45	0.15 to 0.25	0.45 to 0.55	0.15 to 0.25	0.25 to 0.35	0.95 to 1.10
Manganese	0.40 to 0.70	0.70 to 1.00	0.40 to 0.70	0.65 to 0.95	0.65 to 0.95	0.65 to 0.95	0.25 to 0.55
Phosphorus, max	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sulfur, max	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Silicon	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80	0.20 to 0.80
Nickel	1.65 to 2.00	1.65 to 2.00	1.65 to 2.00	...	0.40 to 0.70	0.40 to 0.70	...
Chromium	0.70 to 0.90	0.70 to 0.90	...	0.80 to 1.10	0.40 to 0.70	0.40 to 0.70	1.30 to 1.60
Molybdenum	0.20 to 0.30	0.20 to 0.30	0.20 to 0.30	...	0.15 to 0.25	0.15 to 0.25	...
Vanadium	...	...	...	0.15 min	...	...	...
Residual Elements:							
Copper	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nickel	...	...	...	0.50	...	...	0.50
Chromium	...	...	0.35	...	...	...	...
Molybdenum + Tungsten	...	...	...	0.10	...	...	...
Tungsten	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total content of unspecified elements	0.60	1.00	1.00	1.00	1.00	1.00	0.60

[A] Investment Casting (IC) numbers are to be used only for nomenclature comparison.

TABLE 2 Chemical Requirements

Type	Grade 21	Grade 31
Carbon	0.20–0.30	0.45–0.55
Manganese	1.00 max	1.00 max
Silicon, max	1.00	1.00
Phosphorus, max	0.040	0.040
Sulfur, max	0.040	0.040
Chromium	25.00–29.00	24.50–26.50
Nickel	1.75–3.75	9.50–11.50
Cobalt	remainder	remainder
Molybdenum	5.00–6.00	. . .
Tungsten	. . .	7.00–8.00
Vanadium	. . .	. . .
Columbium + tantalum	. . .	. . .
Nitrogen	. . .	. . .
Iron	3.00 max	2.00 max
Boron	0.007 max	0.005–0.015

analysis shall be made from a test sample taken preferably during the pouring of the heat, or from a master heat (Note 2) which is remelted with only minor additions for deoxidization. The chemical composition determined from the heat or master heat shall be reported to the purchaser, or his representative, and shall conform to the requirements in Table 1.

NOTE 2—A master heat is refined and alloyed metal of a single furnace charge, not exceeding 10 000 lb [4500 kg].

5.3 *Product-Check-Verification Analysis*—A product analysis may be made by the purchaser from material representing each heat, lot, or casting. The analysis shall be made on representative material. Due to the possibility of decarburization, carbon and alloy steel samples for carbon analysis shall be taken no closer than ¼ in. [6.4 mm] to a cast surface except that castings too thin for this shall be analyzed on representative material. The chemical composi-tion thus determined shall meet the requirements specified in Table 1 and Table 2.

5.4 *Referee Analysis*—Test Methods E 30 and E 350 shall be used for reference purposes. When a comparison is made between the heat analysis and product analysis, the reproducibility data, R_2, in the precision statement of Test Methods E 350 shall be used as a guide.

6. Workmanship, Finish, and Appearance

6.1 The castings shall conform substantially to the shapes and sizes indicated by the patterns and drawings submitted by the purchaser. Casting tolerances or deviations from drawing dimensions shall be agreed upon between the purchaser and the

manufacturer and shall be on the drawing.

7. Quality Assurance

7.1 The surface of the casting shall be examined visually and shall be free of adhering refractory, scale, cracks, hot tears, and other injurious imperfections. Castings may have a gate evidence of 0.03 in. [0.8 mm] maximum on surfaces subject to subsequent machining and 0.01 in. [0.3 mm] maximum on the surfaces not subject to machining.

7.2 When additional inspection is desired, Supplementary Requirements S4, S5, or S6 may be ordered.

7.3 The castings shall not be peened or plugged or impregnated to stop leaks.

8. Repair by Welding

8.1 Repairs shall be made using procedures and welders qualified under Practice A 488/A 488M.

8.2 Welding shall be accomplished with a filler metal that produces a weld deposit with a chemical composition similar to the casting. Castings ordered in the annealed condition or for subsequent hardening shall be annealed after weld repairs. Castings ordered heat treated shall be tempered in accordance with the qualified welding procedure after weld repairs with the exception of Grades 1A and 2A where postheat treatment is optional.

8.3 Welds shall be inspected to the same quality standards as are used to inspect the castings.

9. Inspection

9.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Foundry inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections with the exception of product analysis (see 5.3) shall be made either at the place of manufacture or a laboratory with the capability to perform analyses or mechanical tests to the applicable ASTM specifications.

10. Rejection and Rehearing

10.1 Any rejection based on tests made in accordance with 5.3 shall be reported to the manufacturer within 30 days from receipt of samples by the purchaser.

10.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works may be rejected, and the manufacturer shall be notified.

10.3 Castings rejected in accordance with this specification shall be made available to the manufacturer for his review and concurrence.

11. Certification

11.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with the specification (including year date), together with a report of the test results, shall be furnished at the time of shipment.

12. Product Marking

12.1 Castings shall be marked for identification as agreed upon by the manufacturer and the purchaser.

13. Keywords

13.1 steel castings; investment castings; carbon steel; alloy steel; cobalt alloys

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and the purchaser.

S1. Residual Elements

S1.1 The manufacturer shall determine the percentage of residual elements shown in Table 1 and Table 2 and report these results to the purchaser or his representative.

S3. Tension Test (Castings Heat-Treated by Manufacturer)

S3.1. Tensile properties shall be determined from material representing each heat. The bar from which the test specimen is taken shall be heat-treated with production castings to the same procedure as the castings it represents. The results shall conform to the requirements specified in Table 3, or to properties agreed upon, and shall be reported to the purchaser or his representative.

S3.2 The test specimens shall be cast in the same type mold as the casting. They may be cast to shape or machined from blocks. The specimens shall be machined to dimensions in accordance with Test Methods and Definitions A 370 or the ICI bar shown in Fig. 1. Tension tests shall be performed in accordance with Test Methods and Definitions A 370.

S3.3 If the results of the mechanical test for any heat do not conform to the requirements specified, the castings may be reheat-treated and retested. If any test specimen shows defective machining or develops flaws, it may be discarded, and another specimen substituted from the same heat.

S4. Magnetic Particle Inspection

S4.1 The casting shall be examined by magnetic particle inspection. The method of performing the magnetic particle test shall be in accordance with Practice E 709. The types and degrees of discontinuities considered may be judged by Reference Photographs E125. The extent of the examination and the basis for acceptance shall be subject to agreement between the manufacturer and the purchaser.

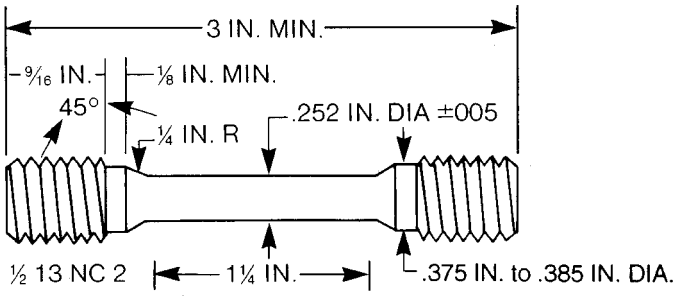
S5. Radiographic Inspection

S5.1 The casting shall be examined for internal defects by

TABLE 3 Tensile Requirements

Grade	Tensile strength, min		Yield strength, min		Elongation, in 2-in. [50-mm] or 4 diameters	Heat Treatment
	ksi	[MPa]	ksi	[MPa]		
1A	60	[414]	40	[276]	24	A[A]
2A	65	[448]	45	[310]	25	A
2Q	85	[586]	60	[414]	10	QT[B]
3A	75	[517]	48	[331]	25	A
3Q	100	[689]	90	[621]	10	QT
4A	90	[621]	50	[345]	20	A
4Q	125	[862]	100	[689]	5	QT
5N	85	[586]	55	[379]	22	NT[C]
6N	90	[621]	60	[414]	20	NT
7Q	150	[1030]	115	[793]	7	QT
8Q	180	[1241]	145	[1000]	5	QT
9Q	150	[1030]	115	[793]	7	QT
10Q	180	[1241]	145	[1000]	5	QT
11Q	120	[827]	100	[689]	10	QT
12Q	190	[1310]	170	[1172]	4	QT
13Q	105	[724]	85	[586]	10	QT
14Q	150	[1030]	115	[793]	7	QT
15A[D]	...	...	...	...	...	A

[A] Annealed.
[B] Quenched and tempered.
[C] Normalized and tempered.
[D] Hardness Rockwell B, 100 max.



Metric Equivalents

in.	0.005	1/8	0.252	0.375	0.385	9/16	1 1/4	3
[mm]	[0.15]	[3]	[6.40]	[9.50]	[9.75]	[15]	[30]	[75]

FIG. 1 Design and Dimensions of the ICI Test Bar

means of X rays or gamma rays. The inspection procedure shall be in accordance with Guide E 94, and the types and degrees of defects considered shall be judged by Reference Radiographs E 446 or E 192. The extent of examination and the basis of acceptance shall be subject to agreement between the manufacturer and the purchaser.

S6. Liquid Penetrant Inspection

S6.1 The casting shall be examined by liquid penetrant inspection. The method of performing the liquid penetrant test shall be in accordance with Practice E 165. The extent of the examination, the methods and types of penetrants to be used, the developing procedure, and the basis for acceptance shall be subject to agreement between the manufacturer and the purchaser. There are no ASTM reference standards for investment castings for liquid penetrant examination.

S19. Mechanical Properties

S19.1 Mechanical properties other than those specified in Table 3 may be ordered for each of the grades. The properties shall be agreed upon between the manufacturer and the purchaser.

S25. Tension Test (Castings Heat-Treated by Purchaser)

S25.1 The manufacturer shall heat-treat a tension specimen from the same heat to determine whether the castings are capable of being heat-treated to the specified properties. The results shall conform to the requirements specified in Table 3, or to properties agreed upon, and shall be reported to the purchaser or his representative.

S25.2 The test specimens shall be cast in the same type mold as the casting. They may be cast to shape or machined from blocks. The specimen shall be machined to dimensions in accordance with Test Methods and Definitions A 370 or the ICI bar shown in Fig. 1. Tension tests shall be performed in accordance with Test Methods and Definitions A 370.

S25.3 If the results of the mechanical test for any heat do not conform to the requirements specified, an additional test

bar may be reheat-treated and retested, but no more than two retests shall be permitted. If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted from the same heat.

S26. High Temperature Tension Test

S26.1 High-temperature tension tests shall be required when specified in the inquiry, contract, or order. When so specified, the properties obtained shall be reported to the purchaser or his representative and shall conform to the requirements prescribed in Table S26.1 . The tension test shall be performed in accordance with Test Methods E 21.

S27. Stress Rupture Test

S27.1 Stress rupture tests shall be required when specified in the inquiry, contract, or order. When so specified, the properties obtained shall be reported to the purchaser or his representative and shall conform to the requirements prescribed in Table S27.1. The stress rupture test shall be performed in accordance with Practice E 139.

TABLE S26.1 Elevated-Temperature Tensile Requirements

Grade	21	31
Condition	as cast	as cast
Test temperature:		
°F	1500	1500
°C	820	820
Tensile strength, min:		
ksi	52.0	55.0
MPa	360	380
Elongation in 4*D*, min, %	10	10

TABLE S27.1 Stress Rupture Requirements

Grade	21	31
Condition	as cast	as cast
Test temperature:		
°F	1500	1500
°C	820	820
Stress:		
ksi	23.0	30.0
MPa	160	205
Rupture life, min, h	15	15
Elongation in 4*D*, min, %	5	5

APPENDIX

(Nonmandatory Information)

X1. GUIDE TO CLASSIFICATION OF COBALT ALLOY CASTINGS

X1.1 This guide is appended to the specification as a source of information; it is not mandatory and does not form a part of the specification.

X1.1.1 This specification itself is intended to provide both the manufacturer and the purchaser of alloy castings with a means of production control on the basis of acceptance through mutually acceptable, sound, standard requirements.

X1.1.2 This guide has been prepared as an aid to prospective users of alloy castings covered by the specification in determining the classification best suited for a particular application with due consideration to the particular requirements for that application.

X1.2 *Stress for Design*—The old method of basing design calculations on 50 % of the limiting creep stress is conservative, but it is relatively crude and has the disadvantage that the resulting stress values do not have a consistent relation to life expectancy. Design with the stress that should produce rupture in 100 000 h is frequently satisfactory, though it should be recognized that this is an extrapolated value and provides no assurance that the installation will actually endure for this time. Among the factors that can result in shorter life are reduction of the effective cross-sectional area by hot-gas corrosion, thermal stresses superimposed on the normal working stresses, and overheating. Usually overheating is the most serious of these, since in general a 200°F [110°C] increase in temperature will cut the rupture strength in half.

X1.3 *Grade 21 (Cobalt-base—27 % Cr, 5.5 % Mo, 2.8 % Ni):*

X1.3.1 This grade is resistant to oxidizing and reducing atmospheres at temperatures up to 2100°F [1150°C]. The alloy has good strength at elevated temperatures and is used in many applications where resistance to thermal shock is important. The alloy can be produced as sand, shell, or investment castings.

X1.3.2 *Composition*—This grade is of the austenitic, solid solutioning type and possesses its basic strength characteristics without the need of heat treatment. However, the alloy is so designed that aging occurs in the 1300 to 2100°F [700 to 1150°C] range by the formation of carbides, thus strengthening the alloy in service. The high chromium imparts the excellent oxidation resistance of the alloy and contributes, along with the molybdenum, to the strength of the alloy.

X1.3.3 *Mechanical Properties*—This grade can be used for applications of high stress up to 1500°F [815°C] and moderate strength requirements to 2100°F [1150°C]. The average as-cast tensile strength at 1500°F is 62 000 psi [430 MPa] with 16 % elongation. The alloy exhibits good impact strength even in the age-strengthened condition. The average Charpy *V*-notch impact strength after aging is above 20 ft·lb [27 J] in the 1200 to 1800°F [650 to 980°C] range. Table X1.1 contains typical stress-rupture data for this alloy.

X1.3.4 *Applications*—This grade can be used for applications of high stress up to 1500°F and for moderate strength requirements up to 2100°F. In the past, it has been used successfully for gas turbine blades and vanes, as well as for turbosupercharger blading applications.

TABLE X1.1 Typical Stress-Rupture Data for Grade 21

Test Temperature		Average Initial Stress for Rupture							
°F	°C	10 h		100 h		500 h		1000 h	
		psi	MPa	psi	MPa	psi	MPa	psi	MPa
1400	760	42 000	290	24 000	165	18 000	124	15 000	103
1500	815	27 500	189	19 000	131	15 000	103	13 500	93
1700	925	17 000	117	13 000	90	10 800	74	10 000	69
1800	980	12 500	86	9 400	65	7 700	53	7 000	48

X1.4 *Grade 31 (Cobalt-base—25.5 % Cr, 10.5 % Ni, 7.5 % W):*

X1.4.1 This grade has been one of the most useful high-temperature alloys in the past. The alloy is used for high-strength applications to about 1500°F [815°C] and moderate-strength applications to 1800°F [980°C]. It has excellent oxidation resistance, thermal shock resistance, and fatigue life. The alloy can be produced as a sand, shell, or investment casting.

X1.4.2 *Composition*—This grade is the austenitic, solid solutioning type and possesses its basic strength characteristics without the need of heat treatment. However, the alloy is so designed that aging and strengthening occur in service through the precipitation of carbides. Also, it is sometimes necessary to employ a solution heat-treatment for heavy sections of castings to develop optimum strength.

X1.4.3 *Mechanical Properties*—Until the introduction of the vacuum-melted nickel-base, precipitation-hardening alloys, the solid solution cobalt-base alloys were considered the stronger of the available engineering materials for high temperature applications. At 1500°F [815°C] this grade has an average as-cast tensile strength of 63 200 psi [43.5 MPa] and an elongation of 15 %. The combination of strength with high ductility is an advantage over other alloys which exhibit ductilities in the order of 5 % or less. Table X1.2 contains typical stress-rupture data for this alloy.

X1.4.4 *Applications*—This grade can be used for applications of high stress up to 1500°F [816°C] and for moderate strength requirements up to 2100°F [1149°C]. In the past, it has been used extensively for blading and vanes for gas turbine and turbosuperchargers.

TABLE X1.2 Typical Stress-Rupture Data for Grade 31

Test Temperature		Average Initial Stress for Rupture							
°F	°C	10 h		100 h		500 h		1000 h	
		psi	MPa	psi	MPa	psi	MPa	psi	MPa
1350	730	49 000	338	44 000	303	40 000	276	39 000	269
1500	815	33 000	228	27 000	159	23 000	159	22 000	152
1700	925	20 000	138	17 000	117	15 400	106	14 500	100
1800	980	13 000	90	11 300	78	10 200	70	9 800	68